Electromagnetic Induction

"Concepts without factual content are empty; sense data without concepts are blind.... The understanding cannot see. The senses cannot think. By their union only can knowledge be produced."

I. Kant

OBJECTIVE

To observe currents induced by a changing magnetic field.

THEORY

About 1820 the Danish physicist Oersted noticed that a wire carrying an electric current produced a magnetic field. It occurred to Michael Faraday to ask the converse question: Is a current produced by a magnetic field in the vicinity of a wire? The answer he found is yes, but only if the field is changing. Faraday's results can be summarized in a simple form for a loop of wire by the equation

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

(1)

Here $\mathcal{E}$ is the induced voltage measured at a gap in the loop and Φ_B is the magnetic flux through the loop. The voltage is evidently proportional to the rate of change of the flux.

In general, the flux is given by

$$\Phi_B = \int \vec{B} \bullet d\vec{A}$$

(2)

where the integral runs over the area of the loop. To gain some intuition about flux, consider a loop in a uniform magnetic field $\vec{B}$. Then the flux through the loop is given by

$$\Phi_B = BA\cos\theta$$

(3)

where A is the area of the loop and θ is the angle between $\vec{B}$ and a perpendicular to the plane of the loop. In a sense, then, flux is the "amount" of magnetic field which goes straight through the loop. The direction of the perpendicular, which determines θ and the sign of the flux, is given by

an arbitrary rule: Imagine standing on the surface and walking around the loop with the inside of the loop to your left. The perpendicular points from your feet toward your head.

If the loop is part of a complete circuit, so that current can flow, an additional magnetic flux will be produced by the induced current. The negative sign in Faraday's law tells us that the flux produced by the induced current opposes the change in the external flux. This result is called Lenz's law, and often provides an easy way to find the direction of the induced current or voltage.

The magnetic flux through a loop might change for a variety of reasons: Motion of a magnet relative to the loop; Motion of a current-carrying wire relative to the loop; A changing current in a nearby wire; A changing current in the loop itself. In this experiment we will qualitatively investigate the first three effects, leaving the last case of "self-inductance" for another day.

EXPERIMENTAL PROCEDURE

The voltages and currents we can induce by moving ordinary magnets or changing reasonable currents are rather small. Accordingly we will need to use coils of many turns, rather than a simple loop, and a sensitive DC meter, called a galvanometer, to detect the currents. Your lab station is also supplied with some coils, a magnet, a current source, and a compass to determine the direction of the fields.

Since the galvanometer is very delicate, it is easily damaged by excessive current. **Do not, under any circumstances, connect the galvanometer to the power supply in any way.** There is no need to do so, and the (expensive) instrument will be instantly destroyed. You should also be aware that strong magnetic fields will influence the galvanometer reading, so keep magnets away from it.

The first task is to determine the polarities of the meter, the magnet and the coil. Since these are not obvious, we will need to do some tests. For the galvanometer, we will accept the manufacturer's claim: When current enters the red or "+" terminal of the galvanometer, it deflects to the right. **(Do not attempt to verify this with the power supply!)**


Magnet and compass polarity

By convention, magnetic field lines come out the north pole of a magnet and enter the south pole. The compass's "north pole" is the end of the compass needle which points to the Earth's physical North Pole. Move your compass away from all iron and magnets, and note which end points toward the Earth's physical North Pole, and that end is the north pole of the compass needle. (For reference, McMurtry College is almost exactly north of Herzstein Hall.) Now that you know which end of the compass needle is its north pole, you can check the N and S

markings on the bar magnet. **Remembering that opposite magnetic poles attract.** A magnet can reverse polarity if brought close to another sufficiently strong magnet, so it is always reasonable to check an unknown magnet.
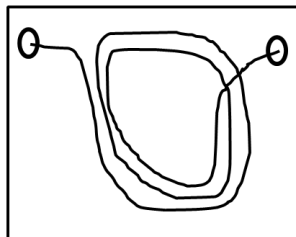
Coil winding direction

The winding direction of the coil can be found by a similar trick even if the wires are not clearly visible. Connect the power supply to the large coil so that current comes out of the red terminal of the power supply, goes through the coil and returns to the black terminal of the power supply. **The galvanometer is not part of this circuit.** Use the compass to determine the direction of the magnetic field due to the current, and then use the right-hand rule for magnetic fields to determine which way the current is flowing around the coil. This also tells you how the wire loops are winded. Your coil could be winded clockwise or counterclockwise, the difference between the two types of winding is illustrated in figure 1 below. The front side of the large coil is the side where the plugs for the wires are located. Draw the winding direction of your large coil and explain how it was determined. (**Note: the winding direction of the coil is fixed at the factory, but the current direction varies depend on how the large coil is connected to the power supply by you.**)

Front side view of the coil
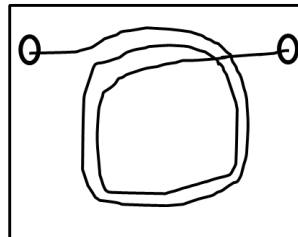
Clockwise winding

Front side view of the coil

Counter-clockwise winding

Fig. 1 Types of Winding Direction for the Coil

Magnet and coil

You are now ready to use a moving magnet to induce a current in the coil of wire. **Remove the power supply** and connect the large coil to the galvanometer. Now move the bar magnet in and out of the center of the coil with the axis of the magnet parallel to the axis of the coil. You should see an obvious deflection of the galvanometer needle. Describe what happens when you move the magnet more or less quickly, and when you put the north or south pole into the coil first. Then try other relative motions and positions, including some where the axes of the magnet and the coil are perpendicular. Does it make a difference if you move the coil, rather than the magnet, in the same relative motion? (Do this carefully, as the coils are heavy and somewhat fragile.) In your report, clearly describe the motions you used, what flux changes they should produce, and how the observed current can be explained by using Faraday's law and/or Lenz's law. Some sketches will probably help your explanation. When describing the current induced in the large coil, describes it in terms of going clockwise or counter-clockwise as viewed from the side of the large coil where the wires are plugged into the top corners of the large coil.

Small coil as magnet

When you have completed your work with the bar magnet, you can try some of the same tests with a current-carrying coil. Connect the small coil to the power supply, and use the compass to determine the direction of its field. Move the small coil in and out of the large coil, while the large coil is connected to the galvanometer, and note the deflections of the galvanometer. Are the results consistent with your earlier observations on the bar magnet? What happens if you reverse the direction of current in the small coil by reversing the power supply connections? As before, be sure your explanations are clear and concise. When describing the current induced in the large coil describes it in terms of going clockwise or counter-clockwise as viewed from the side of the large coil where the wires are plugged into the top corners of the large coil.

Since the small coil is a magnet only when current is flowing, we can look at the effect of turning a magnet off or on, without any other motion. Place the small coil inside the large one, and switch the power supply on and off. How does the galvanometer deflect? Explain the deflection in terms of Faraday's law or Lenz's law.